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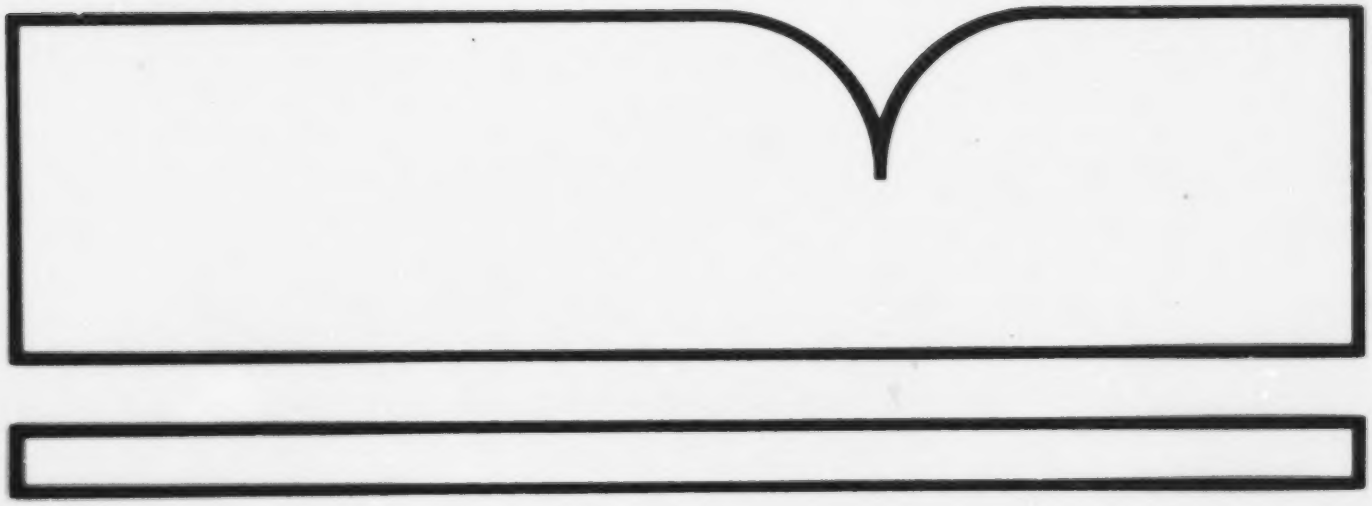

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EFFECTS OF ACID PRECIPITATION ON MICROBIOLOGICAL AND CHEMICAL PARAMETERS IN SOILS: THE FLORIDA EXPERIENCE

Gabriel Bitton*, B.G. Volk**, D.A. Graetz**, and G.E. Byers**,

*Laboratory of Environmental Microbiology
Department of Environmental Engineering Sciences,
and **Soil Science Department
University of Florida
Gainesville, Florida 32611

ABSTRACT

The effects of acid precipitation on microbiological and chemical parameters in soils were investigated under field conditions. The study site consisted of three transects, each including three 75 m^2 plots. One transect served as a control, the second one was irrigated with acid rain at pH 3.7 and the third one received acid rain at pH 3.0. Acid rain did not significantly alter enzyme activity, except for protease activity which increased at pH 3.0. Soil respiration was not significantly altered by acid treatment. However, nitrification rate was significantly reduced by acid precipitation at pH 3.7 and 3.0. Acid rain did also lead to substantial leaching of divalent cations such as Ca^{2+} and Mg^{2+} but did not affect the transport pattern of monovalent cations such as K^{+}.

INTRODUCTION

During the past 25 years, we have witnessed an increasing acidity of rain falling over the eastern portion of the United States, eastern Canada, and western Europe (Babich et al., 1980; Cogbill and Likens, 1974). Acid precipitation is primarily associated with industrial and car emissions of sulfur and nitrogen oxides (Babich et al., 1980). These emissions result in the acidification of rain with H_2SO_4 and HNO_3.

Acid precipitation may affect both the aquatic and terrestrial environments. In aquatic systems, acid rain may affect bacteria, phytoplankton, zooplankton, and fish populations as well as alter predator-prey relationships (Haines, 1981). Lakes may also be subjected to toxic concentrations of Al and other metals leaching from the surrounding watersheds (Cronan and Schofield, 1979; Hendrey et al., 1976; Wright and Gjessing, 1976). The impact of acid precipitation on terrestrial environments may result in chemical and biological alterations.

Many Entisols, especially quartzipsamments, in the eastern United States are sensitive to acid precipitation. In Florida, approximately 35%

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of the northern half of the state is covered by these types of soils. The largest acreage of citrus production in Florida is on the "sand hills of central Florida." Acid precipitation could remove significant quantities of bases and micronutrients from these soils. Investigators have noted the leaching of these elements from soils treated with acid precipitation (Strayer and Alexander, 1981; Bache, 1980; Wilson, 1980).

Losses of bases from soils used for forest production would be particularly damaging to forest productivity in that the basic cations are not applied to forest plantations. Johnson et al. (1981), in an examination of tree growth rates on a New Jersey Hapludult and Quartzipsamment have suggested that acid precipitation may be having a deleterious effect on tree growth.

Acid rain may also lead to alterations of microbiological processes in soils. Those of most concern are N transformations in soils (Alexander, 1980). Much of the data available on the impact of acid rain on soil microbiological processes have been obtained through laboratory studies (e.g., Bryant et al., 1979; Francis et al., 1980; Strayer and Alexander, 1981; Strayer et al., 1981). However, little is known about the effects of acid rain on soil microbial activity under field conditions.

The objective of this study was to examine the impact of acid precipitation on microbiological and chemical processes on Florida soils under field conditions.

MATERIALS AND METHODS

Site description

The study site was located in the Ordway Preserve, 3 miles east of Melrose, Florida. This preserve belongs to the University of Florida and has been solely used for the acidification study. The study site was located on the south side of Lake McCloud, an ultra oligotrophic lake. The soil prevailing in the site was a typic quartzipsamment and belongs to the Candler series (97.0% sand, 1.9% silt, 1.1% clay, 0.73% organic carbon, pH = 4.5).

The study site consisted of three transects, each including three 75 m^2 plots. The transects extended from the near shore of Lake McCloud uphill to a distance of 120 meters on a 13% slope (Figure 1).

The simulated acid rain consisted of Lake McCloud water acidified to pH 3.7 or pH 3.0 with a mixture of 70:30 H_2SO_4:HNO_3, using a chemilizer dilutor. One treatment was applied per transect. Four sprinklers were installed per plot, one per corner. Flowmeters, pressure gauges, a conductivity bridge and a pH meter were used to monitor water flow, conductivity and pH during each irrigation event. The first series of irrigation events was carried out from March to July 1981, and 50 cm of rain were applied during that period. A second series of irrigation events was carried out from March to August 1982 and consisted of applying 100 cm of rain over a 6-month period.

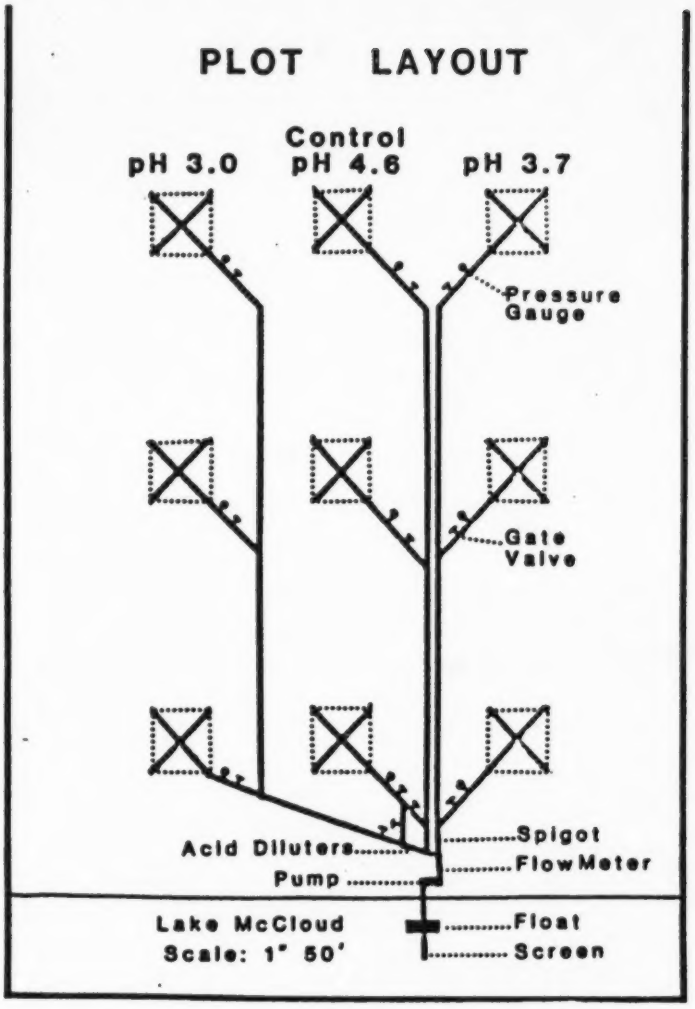


FIG. 1 Plot layout for the acidification experiment

Soil Chemistry

Suction tube lysimeters placed at 15, 45 and 75 cm depths were sampled after each irrigation event. The soil solutions were analyzed for conductivity, pH, K, Ca, Mg, NH_4, NO_3, SO_4, P and also screened for Cu, Mn, and Al by appropriate atomic absorption or Technicon autoanalyzer colormetric techniques. Soil samples were also collected from the plots and analyzed for pH and extractable nutrients.

Soil Microbiology

The impact of acid rain on enzyme activity was investigated. Five soil samples were taken from the top 1 cm of each plot. Each sample was a composite of 5 subsamples taken randomly from a given plot section. The soil samples were put in Zip-lock bags and brought back to the laboratory for enzyme analysis. Dehydrogenase, protease, phosphatase and urease activities were determined according to published methods (Casida et al., 1964; Bohlen et al., 1973; Tabatabai and Bremner, 1964; McGarity and Myers, 1967). Soil respiration was determined under field conditions by measuring CO_2 evolution in incubation chambers made of PVC columns dug into the soil. These columns were 15 cm in diameter and were sealed at the top with a plexiglass plate covered with aluminum. Carbon dioxide was sampled via a syringe inserted with a septum in the plexiglass cover and measured with the aid of an infrared analyzer (Beckman model 864, Beckman Instruments, Fullerton, CA). Results were expressed as $\mu g\ CO_2/m^2.min$. Four incubation chambers were installed in each plot. Carbon dioxide was sampled in triplicate in each incubation chamber.

Other soil samples (4 per plot) were collected to determine the impact of acid precipitation on nitrogen mineralization and nitrification. The samples were incubated for 19 days and NH_4 and NO_3 levels were determined at the beginning and end of the incubation period.

RESULTS AND DISCUSSION

As previously stated, we have monitored alterations in chemical and microbiological parameters after 50 and 150 cm of acid rain. We will only highlight the results obtained after application of 150 cm of rain.

Effect of acid rain on microbial activity in Candler soil:

Table 1 shows the impact of acid rain on the activity of 4 soil enzymes. Dehydrogenase and phosphatase were not significantly altered by acid rain at pH 3.7 or 3.0. Urease activity was slightly increased at pH 3.7 but was not significantly altered at pH 3.0. There was, however, a slight increase in proteast activity at pH 3.0. These results agree with those found in soil core studies under laboratory conditions (Bitton and Boylan, submitted for publication). Others have found that dehydrogenase activity is not affected following soil exposure to SO_2 pollution for 1 year (Wainwright, 1980). However, the activity of this enzyme may be altered at pH below 3.0 (Killham and Firestone, 1982). The slight increase in protease activity may affect nitrogen mineralization in soils. This will be discussed later on. Table 2 shows that acid rain did not significantly alter soil respiration. These results agree with those of other workers who showed no impact of acid rain on CO_2 evolution (Hovland, 1981; Wainwright, 1980; Wood and Rippon, 1980). It appears that soil respiration is affected at extremely low pH (Bewley and Stotzky, 1981).

The impact of acid precipitation on nitrogen mineralization and nitrification is displayed in Table 3. It was observed that nitrogen mineralization rates decreased at pH 3.7 but slightly increased at pH 3.0. This increase, although not statistically significant, agrees well with the slight increase in protease activity at pH 3.0 (Table 1). Using soil

Table 1: Effect of acid precipitation on enzyme activity *

Soil Treatment	Plot #	Dehydrogenase Activity (µg formazan/g. hr)	Phosphatase Activity (µmoles p-nitrophenyl /g.hr)	Urease Activity (mg NH_4-N/ 100 g. 6 hr)	Protease Activi (0.1 change in fluorescence u /g.hr)
Control plots (pH = 4.5)	1	1.06	29.5	17.6	32.5
	3	1.90	37.0	21.6	46.2
	5	1.97	24.9	17.1	41.8
	Mean	1.64 ± 2.0 A	30.5 ± 11.2 A	18.7 ± 3.1 A	40.2 ± 11.3 A
Plots irrigated with water at pH = 3.7	2	3.31	63.2	34.8	56.8
	4	1.81	27.0	19.3	39.3
	6	0.31	20.7	48.3	26.4
	Mean	1.81 ± 1.62 A	37.0 ± 21.9 A	34.2 ± 26.1 B	39.7 ± 13.5 A
Plots irrigated with water at pH = 3.0	7	1.08	29.9	30.6	47.3
	8	1.29	32.8	25.9	65.7
	9	2.39	31.3	31.9	45.4
	Mean	1.59 ± 0.83 A	31.3 ± 4.8 A	29.5 ± 11.5 AB	52.8 ± 14.9 B

* Values followed by the same letter showed no significant difference (α = 0.05) between the control and acidified plots.

Table 2: Effect of acid rain on soil respiration

Soil Treatment	Mean CO_2 evolution per treatment* ($\mu g\ CO_2/m^2.min$)
Control plots (pH = 4.5)	5537 ± 864 A**
Plots irrigated with acid rain at pH 3.7	6320 ± 2139 A
Plots irrigated with acid rain at pH 3.0	5401 ± 2490 A

* Each treatment included three plots. Four incubation chambers were installed in each plot.

** Values followed by the same letter showed no significant differences (α = 0.05) between the control and acidified plots.

Table 3: Effect of acid precipitation on N mineralization and nitrification rates*

Soil Treatment	N Mineralization rate μg (NH_4 + NO_3)-N/g.day	Nitrification rate μg NO_3-N/g. day
Control Plots (pH = 4.5)	0.22 ± 0.04 a	0.16 ± 0.03 A
Plots irrigated with acid rain at pH 3.7	0.11 ± 0.05 b	0.08 ± 0.04 B
Plots irrigated with acid rain at pH 3.0	0.26 ± 0.05 a	0.06 ± 0.02 B

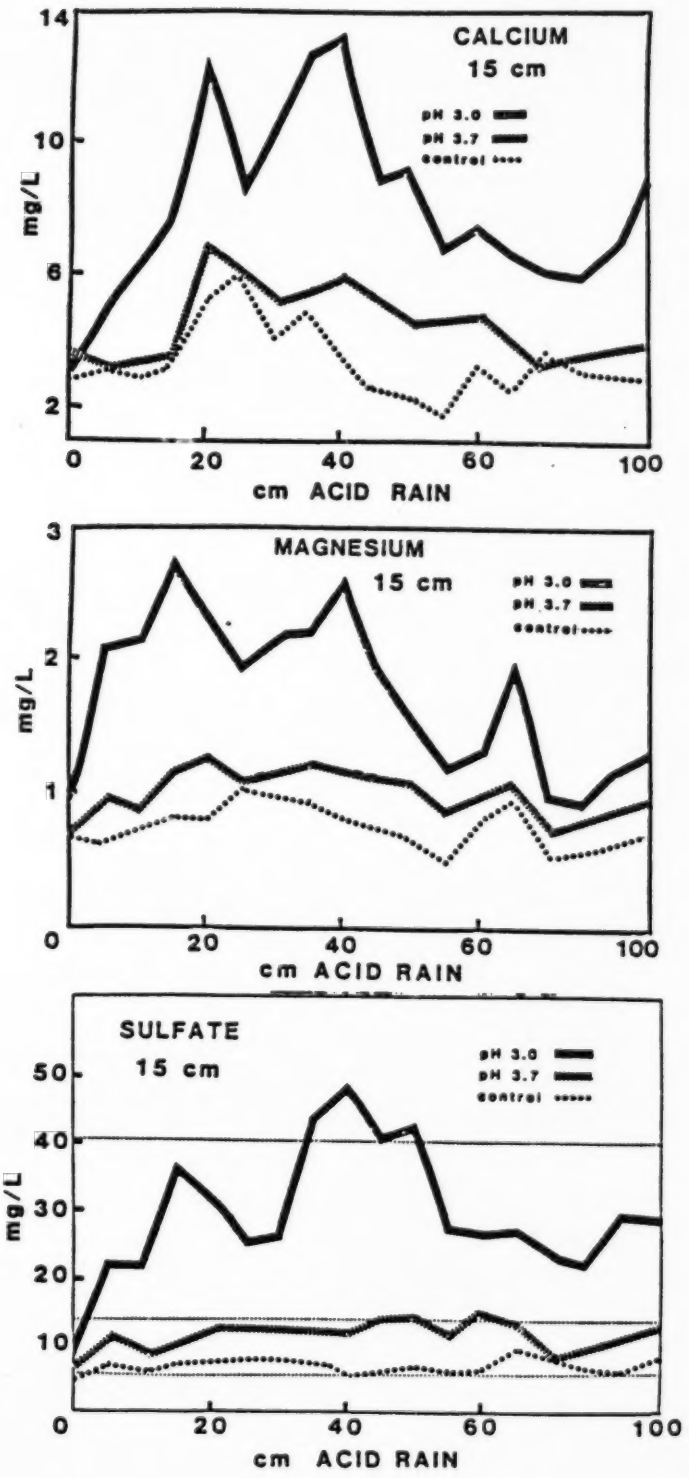
* Values followed by the same letter showed no significant difference (α = 0.05) between the control and acidified plots

columns, Strayer et al. (1981) showed that nitrogen mineralization was either stimulated or unaffected following exposure to acid rain at pH 3.2. Table 3 also shows that the nitrification rate (0.16 μg NO_3-N/g. day) of Candler soil was relatively low but was significantly decreased following exposure to acid rain at pH 3.7 and 3.0. Nitrogen is a major nutrient which may limit plant growth. It has been suggested that among N-transformations, nitrification may be the process the most sensitive to acid precipitation (Alexander, 1980). Strayer et al. (1981) later showed that nitrification decreased when acidity increased only when the soil was amended with NH_4^+. They postulated that heterotrophic nitrifiers which prevail in acid soils were less sensitive to acidification than autotrophic nitrifiers. Our results show that under field conditions, acid rain significantly reduced nitrification even when the soil was not amended with NH_4^+.

Soil Chemistry

Soil leachates taken from 15 cm-depth continued to decrease throughout the duration of the acidification period for both acid rain at pH 3.7 and 3.0. After 100 cm of applied rain, the pH of the leachates from pH 3.0-treated plots was 4.7 as compared to 6.5 for the control plots.

One of the major concerns about acid rain is the leaching of alkaline cations such as Ca^{2+} and Mg^{2+} with subsequent reduction in soil fertility and forest productivity. Figure 2 shows the effect of acid precipitation on the leaching of Ca^{2+}, Mg^{2+} and SO_4^{2-} from Candler soil under field conditions. Throughout the irrigation events, the Ca^{2+} concentration in the soil leachates was consistently higher at pH 3.0 than for both pH 3.7 or the control (Fig. 2A). A calcium peak was observed following 20 to 40 cm of applied rainfall. At 75 cm-depth (Figure not shown) Ca^{2+} concentration peaked only following


CALCIUM
15 cm
pH 3.0
pH 3.7
control
mg/L
14
10
6
2
0
20
40
60
100
cm ACID RAIN
MAGNESIUM
15 cm
pH 3.0
pH 3.7
control
mg/L
3
2
1
0
20
40
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cm ACID RAIN
SULFATE
15 cm
pH 3.0
pH 3.7
control
mg/L
50
40
30
20
10
0
20
40
60
100
cm ACID RAIN

70 cm of applied rainfall. This delayed increase in Ca^{2+} concentration at lower depths indicates the readsorption of calcium originating from the upper soil profile. This trend was not so discernable for the pH 3.7 treatment.

Magnesium also displayed an increased leaching following soil treatment with acid rain at pH 3.7 and 3.0 (Figure 2B). It was observed that Mg^{2+} concentration peaked earlier than Ca^{2+}, indicating a more rapid displacement from the soil exchange sites. This trend has been verified in continuous soil column leaching under laboratory conditions. As noted for Ca^{2+}, there was also a delayed increase in Mg^{2+} concentration at lower depths.

Sulfate adsorption onto soils has been shown to prevent leaching of cations to aquatic ecosystems (Johnson, 1980; Seip, 1980). However, little information is available on the capacity of soils to adsorb sulfate. If sulfate adsorption sites become saturated, cation leaching will proceed unimpeded (Olson et al., unpublished). Sulfate was the major anion added to the acid rain in the form of H_2SO_4. The baseline SO_4 concentrations were 7.3, 14.1 and 40.5 mg/L for control, pH 3.7 and pH 3.0 treatments, respectively. As shown in Figure 2C, the SO_4 concentration of the leachates from control plots was relatively uniform and slightly above the baseline concentration of 7.3 mg/L. For the pH 3.7 treatment, the SO_4 concentration was again relatively uniform with time. For the pH 3.0 treatment, the sulfate concentration was much less uniform and exceeded the baseline concentration (40.1 mg/L) at 40 cm of applied rainfall. The figure further shows that there was sulfate adsorption in the acid-treated soils. Analysis of leachates from the 75 cm-depth showed increased sulfate adsorption with depth. Furthermore, as for Ca^{2+} and Mg^{2+}, sulfate peaked later at the 75-cm depth than at the 15 cm-depth.

Analysis of leachates for monovalent cations such as K^+ showed that acid rain had little impact on K^+ movement through soils. The reason for the differences in transport pattern between monovalent and divalent cations is not known at the present time.

In conclusion, this research has shown that among the microbiological parameters investigated, nitrification is the most sensitive to acid rain. With regard to chemical parameters, the leaching of alkaline cations following acid treatment is of great concern. More research is needed to better understand the impact of acid rain on cation transport through soils.

ACKNOWLEDGEMENT

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REFERENCES

Alexander, M. (1980). Effects of acid precipitation on biochemical activities in soil. IN: Proceedings International Conference Ecological Impact Acid Precipitation, Norway. SNSF Project, pp. 47-52.

Babich, H., Davis, D.L., Stotzky, G. (1980). Acid precipitation: Causes and consequences. Environment, 22: 6-41.

Bache, B.W. (1980). The acidification of soils. pp. 183-202. IN: Hutchinson, T.C. and M. Havas (eds.). Effects of Acid Precipitation on Terrestrial Ecosystems. New York: Plenum Press.

Bewley, R.S.F. and Stotsky, G. (1981). Effects of simulated acid rain and heavy metals on respiration and growth of microbes in soil. Meeting, American Society Microbiol., Dallas, TX.

Bohlen, P., Stein, S., Dairman, W., and Udenfriend, S. (1973). Fluorometric assay of proteins in the nanogram range. Archives of Biochemistry and Biophysics, 55: 213-220.

Bryant, R.D., Gordy, E.A., and Laishley, E.J. (1979). Effect of soil acidification on the soil microflora. Water, Air, and Soil Pollution, 11: 437-445.

Casida, L.E., Jr., Klein, D.A., and Santoro, T. (1964). Soil dehydrogenase activity. Soil Sci., 98: 371-376.

Cogbill, C.V., Likens, G.E. (1974). Acid precipitation in the northeastern United States. Water Resources Research, 10: 1133-1137.

Cronan, C.S. and Scholfield, C.L. (1979). Aluminum leaching response to acid precipitation: Effects on high-elevation watersheds in the Northeast. Science, 204: 304-306.

Francis, A.J., Olson, D., and Bernatsky, R. (1980). Effect of acidity on microbial processes in a forest soil. Proceedings International Conference Ecological Impact Acid Precipitation, Norway, SNSF Project.

Haines, T.A. (1981). Acidic precipitation and its consequences for aquatic ecosystems: A review. Trans. Amer. Fish. Soc., 110: 669-707.

Hovland, J. (1981). The effect of artificial acid rain on respiration and cellulase activity in Norway spruce needle litter. Soil Biol. Biochem., 13: 23-26.

Johnson, D.W. (1980) Site susceptibility to leaching by H_2SO_4 in acid rainfall. pp. 525-528. IN: T.C. Hutchinson and M. Davis (eds). Effects of acid precipitation on terrestrial ecosystems. Plenum Press, New York.

Johnson, A.H., Siccama, T.G., Wang, D., Turner, R.S., and Baringer, T.H. (1981). Recent changes of the growth rate in the New Jersey Pinelands: A possible effect of acid rain. J. Environ. Qual., 10(4): 427-430.

Killham, K., and Firestone, M.K. (1982). Acid rain and soil microbial activity: Effects and mechanisms of effects. Abstract N73, Amer. Soc. Microbiol., Atlanta, GA.

McGarity, J.W., and Myers, M.G. (1967). A survey of urease activity in soils of northern New South Wales. Plant and Soil, 2: 217-238.

Seip, H.M. (1980). Acidification of fresh-water-sources and mechanisms. pp. 358-366. IN: D. Drablos and A. Tollan (eds.). Ecological impact of acid precipitation. Johs. Trefslie Trykkeri A/S. Mysen, Norway.

Strayer, R.F., and Alexander, M. (1981). Effect of simulated acid rain on glucose mineralization and some physicochemical properties of forest soils. J. Environ. Qual., 10: 460-465.

Strayer, R.F., Lin, C.J., and Alexander, M. (181). Effect of simulated acid rain on nitrification and nitrogen mineralization in forest soils. J. Environ. Qual., 10: 547-551.

Tabatabai, M.A., and Bremner, J.M. (1969). Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol. Biochem., 1: 301-307.

Wainwright, M. (1980). Effect of exposure to atmospheric pollution on microbial activity in soil. Plant and Soil, 55: 199-204.

Wilson, S.O. (1980). Actual and potential effects of acid precipitation on a forest ecosystem in the Adirondack mountains. New York State Energy, Research and Development Authority. 242 pp.

Wood, M.J., and Rippon, J.E. (1980). Effect of acid precipitation on soil microbial processes: Pot experiments. IN: Second International Symposium on Microbial Ecology, University of Warwick, Coventry, England.

Wright, R.F., and Gjessing, E.T. (1976). Acid precipitation: Changes in the chemical composition of lakes. Ambio., 5: 219-223.

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